BATTERY HEALTH MONITORING SYSTEM LITHIUM-ION BASED ON FUZZY LOGIC

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ABSTRACT

Batteries that can store electrical energy and are easy to carry make them the most practical technology choice as an electricity source. Even so, lithium-ion batteries are not free from the risk of damage when used. Therefore, a Lithium-ion battery health monitoring system was created. This system uses the INA219 sensor as a current and voltage detector and the DS18B20 sensor as a temperature detector. Arduino as a data process. The test results show that all components function well. In battery capacity testing, the highest error was 1.8%. For the DS18B20 sensor as a temperature sensor, an error of 2.4% was obtained. Testing capacity against temperature on the battery when the temperature was 25 C, the current was 485mAh; when the temperature was 44.8 C, the current was 550mAh, there was a difference of 65mAh or 11%. This difference corresponds to the difference in battery capacity. Testing using the Fuzzy Logic method was carried out on 3 batteries with different capacities to obtain the State of Health (SOH) value for each battery. Testing is carried out in real-time, as well as Matlab simulation. In battery test 1, with a capacity of 2200mAh and the highest temperature of 32.1 oC, the device's State of Health (SoH) was 90%, and Fuzzy Matlab was 87.6%. Battery 2, 1500mAh capacity with the highest temperature of 33.4oC obtained State of Health (SOH) of 60%, Fuzzy Matlab 60%. Battery 3 Capacity 2200mAh, Highest temperature 32.2 oC, State of Health (SOH) of 90%, Fuzzy Matlab 87.6%. The test results show that the overall error is still below 5%. A properly functioning Internet of Things (IoT) system can display information on lithium-ion batteries' State of Health (SoH) on devices and smartphones.

Keywords: *Arduino Mega, DS18B20, ESP8266, Fuzzy Logic, Internet of Things*

1. INTRODUCTION

The increasing use of electronic devices in human life has triggered the need for electrical energy sources in electronic devices that can be used anywhere and at any time. One important source of electrical energy is batteries because batteries that can store electrical energy and make it easy to carry are the most practical technological choice for an electrical power supply [1]. Various research has been carried out in battery management (Battery Management System) when battery operational conditions are not appropriate, such as excessive current (Over Current), temperature that is too high (Over Temperature), excessive current when under load conditions (Over-Discharge) [2]. As there are more types of batteries, there are many factors that need to be considered when charging, because each type of battery will have different characteristics, so various charging methods are needed to be more efficient and precise so that the battery can last longer [3]–[5]. Therefore, more active handling of charging and discharging is needed to maintain battery life. The importance of the battery is so crucial that it is necessary to regulate battery performance and battery charging, especially active battery balancing management [6], [7].

Research related to lithium-ion battery health monitoring has been widely carried out, such as monitoring with ultrasonic transducers [8] using error spectrum models [9]; monitoring can also be done remotely using the Internet of Things [10] and based on artificial intelligence [11]. These researchers use an approach that prioritizes monitoring support tools, whereas a monitoring system that integrates reasoning for quality improvement has yet to be discovered. Another area for improvement is that it has not used a combined approach with fuzzy logic to embed natural human reasoning. Therefore, we developed a lithium-ion battery monitoring system based on fuzzy logic for this research.

This problem is the reason for this research to design a fuzzy logic-based lithium ion battery health monitoring system. Fuzzy Logic is a special logic that can be used in any kind of work to express different states. In contrast to Boolean logic which can only represent logical 0 or 1, fuzzy logic can express values from 0 to 1 [12]. The ability of fuzzy logic to work efficiently with some of the available information makes the fuzzy logic method more flexible to use in systems. electronic device controller [13]. In a fuzzy system, the components are divided; fuzzification changes input with a definite truth value (crisp input) into a fuzzy input form. Next is Inference to carry out reasoning using fuzzy input and predetermined fuzzy rules, and the last is Defuzzification to change the fuzzy output into crisp values based on the predetermined membership function.

2. RESEARCH METHODOLOGY

2.1 Hardware Design

Fuzzy Logic-Based Lithium-Ion Battery Health Monitoring System Design is divided into several parts, as explained in the Block Diagram shown in Figure 1. The first part is the battery, which is the object whose health (SoH) is being monitored. Apart from that, there are current (amperes) and voltage (volts) sensors integrated with Arduino. To determine the condition of the battery, a temperature sensor is also added, which is integrated with the Arduino. Temperature changes will greatly affect battery capacity. The data input from the sensor is processed by Arduino. The Arduino also has an LCD installed to display information or data. The Arduino output via UART serial protocol communication will be sent to the ESP32, the goal is for the data received to be sent to smartphones and ThingSpeak via WiFi.

2.1.1 INA219 Module

The INA219 module is a sensor module that functions to measure two parameters at once, namely voltage (volts) and current (amperes). This sensor sends charging and discharging current data to the Arduino's ADC (analog-to-digital converter) to be accumulated in order to calculate the battery capacity. The voltage value is used as a reference for the battery's charge condition.

2.1.2 DS18B20 Module

The DS18B20 module is a temperature sensor that functions as a battery temperature detector. Temperature changes are important to know as a reference for capacity level and battery condition. The temperature sensor reading data is sent to Arduino as Fuzzy Logic input data. Figure 3 shows the configuration of the temperature sensor in the form of the DS18B20 module.

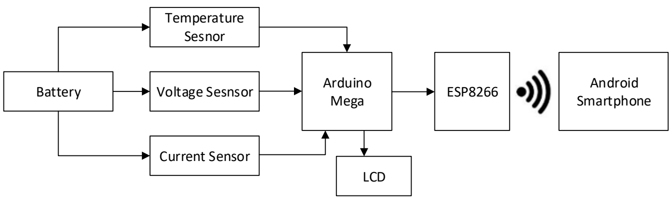

Figure 1. System Block Diagram

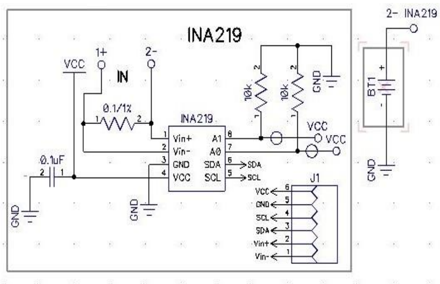

Figure 2. INA219 Module Configuration

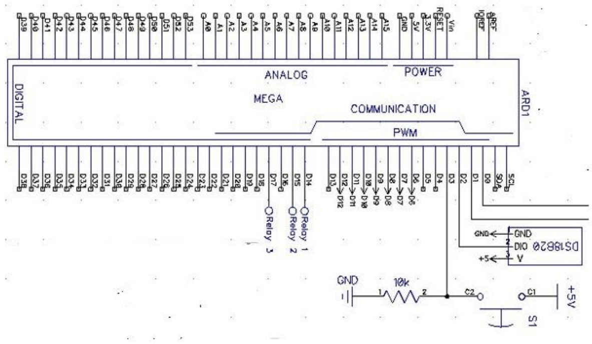

Figure 3. DS18B20 Module Configuration

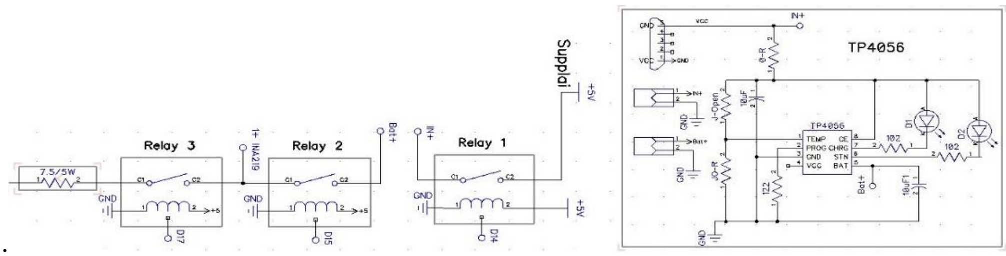

Figure 4. Battery charger circuit configuration.

2.1.3 TP4056 Module

The battery charging process uses the TP4056 module as a charger. To carry out this process, a 5-volt power supply is needed as a charging power source, Arduino is used as a control to regulate when the battery will charge or discharge while loading. The Arduino microcontroller is used to regulate when the battery will charge or discharge with a load. To discharge the battery, a resistor is used as a load. The battery charging circuit configuration is shown in Figure 4

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2.1.4 ESP8266 Module

The ESP8266 module is an additional WiFi module for Arduino and is a medium supporting the Internet of Things (IoT) system with an internet connection. The ESP8266 will periodically send data to the ThingSpeak dashboard. ESP8266 IoT System Configuration as shown in Figure 5.

2.2 Software Design

In this research, the software will regulate the performance of the overall hardware system. This system is integrated with WiFi to send data to ThingSpeak using an Android application with an internet connection. The main software of this system monitors and analyzes battery condition based on the process of reading sensor data. This system applies the Fuzzy Logic Method in Monitoring and Analyzing Battery Health Conditions. Figure 6 is the main program flowchart of the Lithium-Ion Battery Health Monitoring System based on Fuzzy Logic.

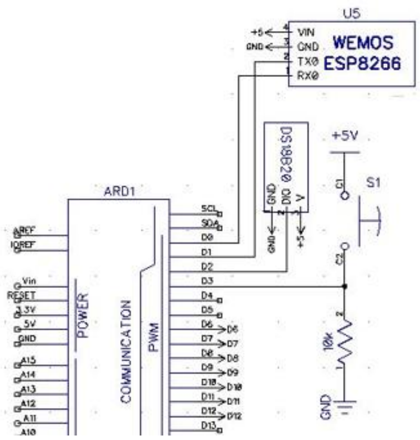

Figure 5. ESP8266 IoT System Configuration

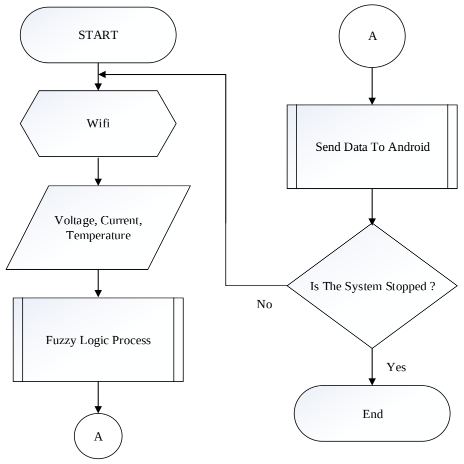

Figure 6. Flowchart System

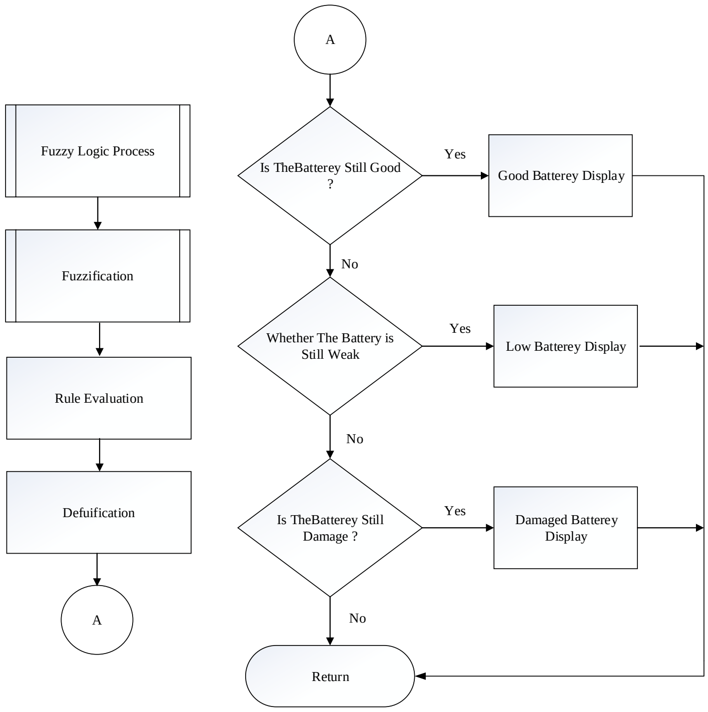

Figure 7. Flowchart of fuzzy logic software on Arduino

2.2.1 Fuzzy Logic Design

In designing Fuzzy Logic Crisp, the inputs used are battery capacity and temperature, as shown in Figure 7. Batteries have a lifespan that decreases over time, thus affecting battery health. Based on Figure 7 the Fuzzy Logic design process for the Lithium-ion battery health monitoring system based on Fuzzy Logic can be explained as follows:

1. **Fuzzification**
   The Fuzzification process uses two inputs, namely Battery capacity and Battery Temperature, while the output is State of Health (SoH). Figure 6 shows a Fuzzification design.

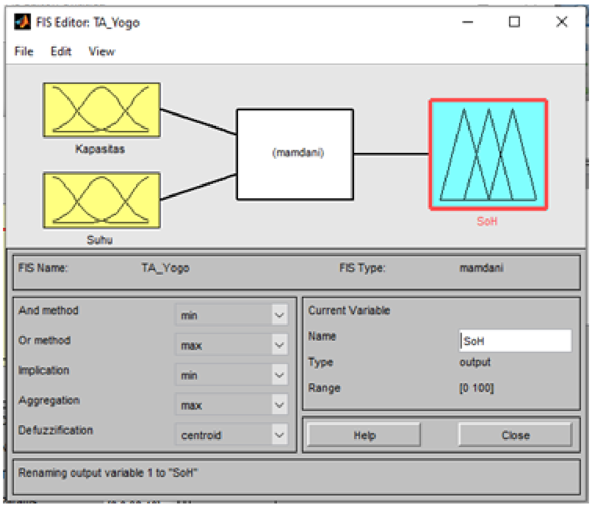

Figure 8. Fuzzy Logic Design

For battery capacity, the fuzzy set shown in Figure 8 is divided into 3 conditions, namely LOW, MEDIUM, and HIGH, with the values for each set as follows:

- LOW Capacity Set

$$f(x) = \begin{cases} 1; & x \leq 30 \\ \frac{40-x}{40-30}; & 30 < x < 40 \\ 0; & x \geq 40 \end{cases} \quad (1)$$

- MEDIU Capacity Set

$$f(x) = \begin{cases} 0; & x \leq 30 \\ \frac{x-30}{40-30}; & 30 < x < 40 \\ 1; & 40 \leq x \leq 70 \\ \frac{80-x}{80-70}; & 70 < x < 80 \\ 0; & 80 \leq x \end{cases} \quad (2)$$

- HIGH Capacity Set

$$f(x) = \begin{cases} 0; & x \leq 70 \\ \frac{x-70}{80-70}; & 70 < x < 80 \\ 1; & x \geq 80 \end{cases} \quad (3)$$

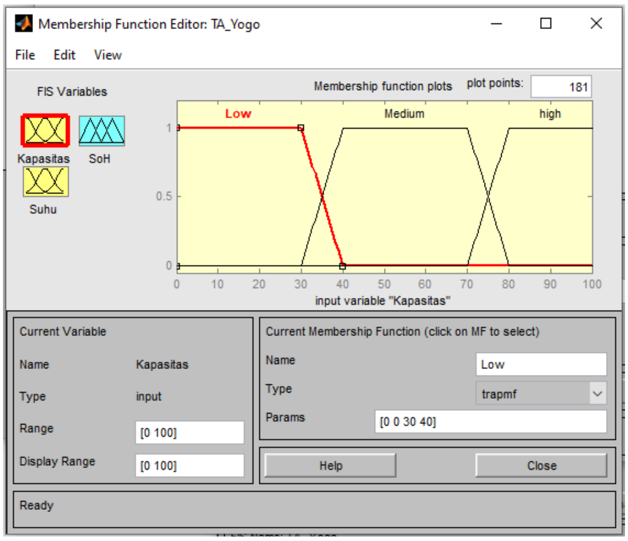

Figure 9. Fuzzy Set of Battery Capacity

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The fuzzy set of temperatures shown in Figure 9 is classified into 3 categories: COLD, NORMAL, and HOT. The set values for each temperature classification are as follows:

- COLD Capacity Set

$$f(x) = \begin{cases} 1; & x \leq 20 \\ \frac{30-x}{30-20}; & 20 < x < 30 \\ 0; & x \geq 30 \end{cases} \tag{4}$$

- NORMAL Capacity Set

$$f(x) = \begin{cases} 0; & x \leq 20 \\ \frac{x-20}{30-20}; & 20 < x < 30 \\ 1; & 30 \leq x \leq 35 \\ \frac{45-x}{45-35}; & 35 < x < 45 \\ 0; & 45 \leq x \end{cases} \tag{5}$$

- HOT Capacity Set

$$f(x) = \begin{cases} 0; & x \leq 45 \\ \frac{x-45}{55-45}; & 45 < x < 55 \\ 1; & x \geq 55 \end{cases} \tag{6}$$

State of Health (SoH) as a fuzzy process output is shown in Figure 10, classified into 3 parts, including DAMAGED, WEAK and GOOD. DAMAGE is classified if the value is below 50%, WEAK if the value is between 40% and 80%, while for GOOD, the SoH value must be more than 70%. The set of fuzzy State of Health outputs is as follows :

- DAMAGE Capacity Set

$$f(x) = \begin{cases} 1; & x \leq 40 \\ \frac{50-x}{50-40}; & 40 < x < 50 \\ 0; & x \geq 50 \end{cases} \tag{7}$$

- WEAK Capacity Set

$$f(x) = \begin{cases} 0; & x \leq 40 \\ \frac{x-40}{50-40}; & 40 < x < 50 \\ 1; & 50 \leq x \leq 70 \\ \frac{80-x}{80-70}; & 70 < x < 80 \\ 0; & 80 \leq x \end{cases} \tag{8}$$

- GOOD Capacity Set

$$f(x) = \begin{cases} 0; & x \leq 70 \\ \frac{x-70}{80-70}; & 70 < x < 80 \\ 1; & x \geq 80 \end{cases} \tag{9}$$

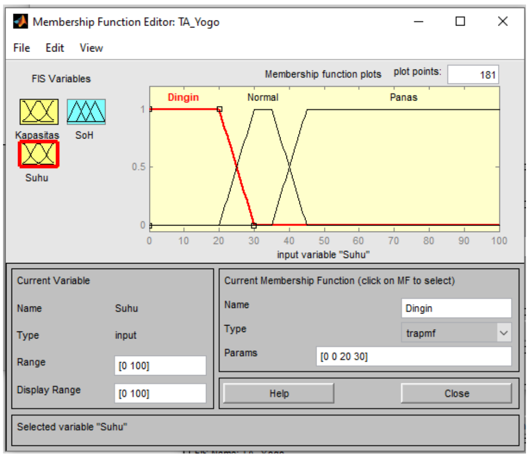

Figure 10. Fuzzy Set of Battery Temperatures.

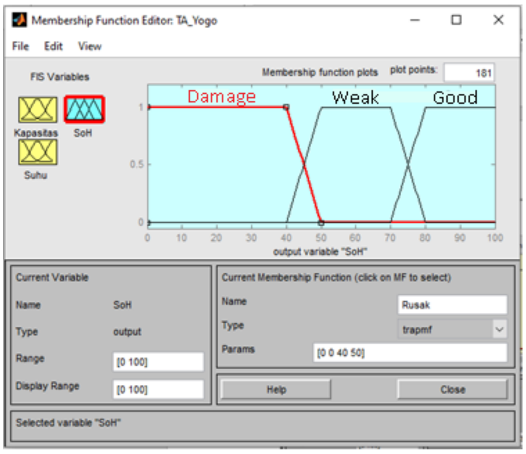

Figure 11. Set of Fuzzy State Of Health Battery

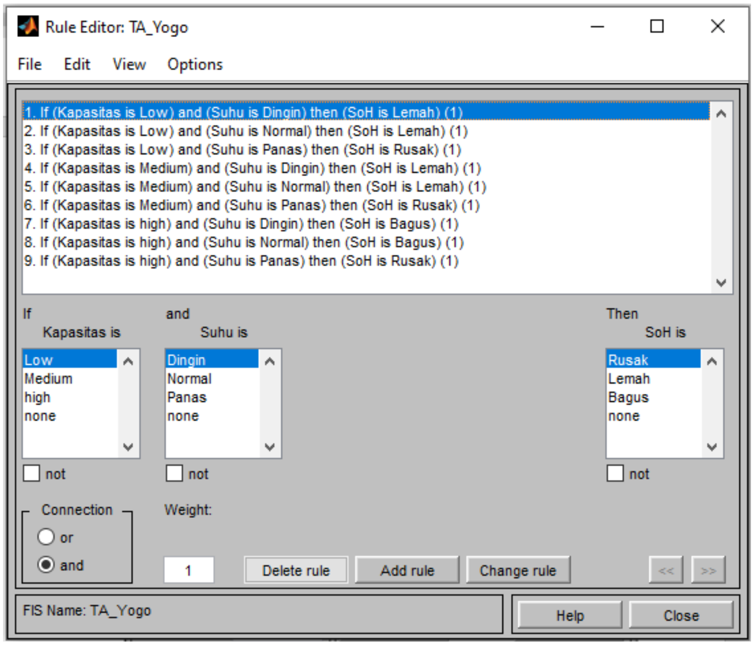

Figure 12. Fuzzy Logic-Based Lithium-ion Battery Health Monitoring System Evaluation Rule.

2. Evaluation Rules

The Evaluation Rule functions to determine all possible combinations of two inputs for making output decisions. There are 9 conditions that occur and each condition must be mapped, and decisions will be taken. Figure 12 is an evaluation rule that has been designed.

3. Defuzzification

This defuzzification uses the Center of Gravity (COG) method :

$$y_i = \frac{\sum_j b_i \int_y \mu_i^j(y)dy}{\sum_j b_i \int_y \mu_i^p(y)dy}$$

$bi = Midpoint\ of\ the\ membership\ function\ area\ for\ the\ pth\ rule$

$\mu i = Degree\ Fuzzy\ Membership$

$yi =$Defuzzification Results

3. RESULTS AND DISCUSSIONS

3.1 Temperature Sensor Testing

The results of measuring the DS18B20 temperature sensor with the Zotek ZT111 temperature sensor on three types of batteries with different capacities are shown in Table 1. This temperature sensor test pattern was carried out by attaching a Zotek ZT111 thermocouple to the DS18B20 temperature sensor to obtain the temperature level at the same point. With this test, you can find out the accuracy level of the DS18B20 temperature sensor. The temperature test results are shown in Table 2.

3.2 Capacity Measurement Test

Testing capacity measurements obtained error values between 8.2% - 9.2%. Errors below 10% are still acceptable or the error tolerance value is ±10%. Errors that are large enough to occur can be caused by different Battery State of Charge (SoC) when measuring capacity using the tool and ZB2L3. The Battery State of Charge is different because the charging module on the tool and the ZB2L3 are different.

3.3 Capacity Testing Against Temperature

In testing battery capacity against temperature, one example of the LG ABB418650 Lithium-Ion Battery was used. The battery temperature specifications are shown in Table 4.

Table 1. Example Battery Specifications

No	Battery Name	Capacity According to Spec	Corrected Capacity
1	Merk A	2200 mAh	Remaining capacity 2100 mAh
2	Merk B	1500 mAh	Remaining capacity 500 mAh
3	Merk C	2200 mAh	Remaining capacity 1700 mAh

Table 2. Result Temperature Testing

No	Battery Name	Zotek Value	DS18B20 Value	Accuracy
1	Merk A	31 °C	31.4 °C	98.7%
2	Merk B	30 °C	30.5 °C	98.4%
3	Merk C	32 °C	32.8 °C	97.6%

A B C

Figure 13. Temperature Testing: Battery (A) Merk A, (B)Merk B, (C)Merk C

Table 3. Result Capacity Measurement Test

NO	Sample	ZB2L3 Capacity Test	Device Capacity	Error
1	Merk A	2309 mAh	2118 mAh	8.2 %
2	Merk B	593 mAh	540 mAh	8.9 %
3	Merk C	2087 mAh	1893 mAh	9.2 %

A B

Figure 14. Testing Battery: (A) Merk A Capacity with ZB213 and (B) with Tools

Table 4. LG ABB418650 Lithium-Ion Battery Temperature Specifications

4.3.5 Temperature Dependency of Capacity	Cells shall be charged per 4.1.1 at 25°C 2°C and discharged per 4.1.2 at the following temperature.		
	Charge	**Discharge**	**Capacity**
	25°C	-10°C	70% of C_{ini}
		0°C	80% of C_{ini}
		25°C	100% of C_{ini}
		60°C	95% of C_{ini}

Table 5. Result Capacity Testing Against Temperature

NO	Batteray exsample	Temperature	Capacity
1	LG ABB418650	25 °C	485 mAh
		44.8 °C	550 mAh

From the tests carried out, with a temperature difference between 25°C and 44.8°C, a difference in capacity of 65 mAh or 11% was observed. This difference corresponds to the variance in battery capacity as outlined in the Battery specifications section. The data results are shown in Table 5.

3.4 Testing the Fuzzy Logic Method

The Fuzzy Logic test in this research was designed with two inputs: battery capacity and battery temperature, and one output in the form of State of Health (SoH) data. It has 9 rules which are a combination of the membership functions of each input. The test pattern is as follows:

- Battery 1 Testing on the Tool
  Capacity Specification = 2200 mAh
  Rated Capacity = 2118 mAh
  Highest Temperature= 32.1 °C
  State of Health (SoH) = 90.0% **(Good)**
- Fuzzy Logic Process
  Capacity Input
  $$Capacity\ (\%) = \frac{Rated\ Capacity}{Capacity\ Specification} \text{ x } 100\%$$
  $$Capacity\ (\%) = \frac{2118}{2200} \text{ x } 100\%$$
  $$Capacity\ (\%) = 96.3\%$$
- Testing with MATLAB :
  Input Temperature = 32.1^{O}C
  SoH Fuzzy Logic Matlab = 87.6%

A B

Figure 15. Measurement of Battery Capacity against Temperature: (A) at 25°C, (B) at 44.8°C.

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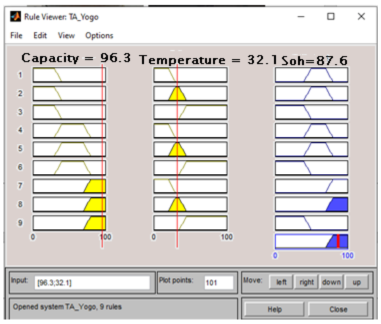

Figure 16. Fuzzy Logic Matlab Battery 1

. Table 6. Battery Testing

Classification	Battery 1		Battery 2		Battery 3	
	Tool	**Fuzzy Logic**	**Tool**	**Fuzzy Logic**	**Tool**	**Fuzzy Logic**
Capacity Specification	2200mAh	2200 mAh	1500 mAh	1500 mAh	2200 mAh	2200 mAh
Rated Capacity	2118mAh	2118 mAh	540 mAh	540 mAh	1893 mAh	1893 mAh
Capacity	96.3%	96.3%	36%	36%	84%	84%
Highest Temperature	32.1 °C	32.1 °C	33.4 °C	33.4 °C	32.4 °C	32.4 °C
State of Health (SoH)	90.0%	87.6%	60.0%	60.0%	90%	87.6%
Condition	Good	Good	Weak	Weak	Good	Good
Error	2,7%		0%		2,7%	

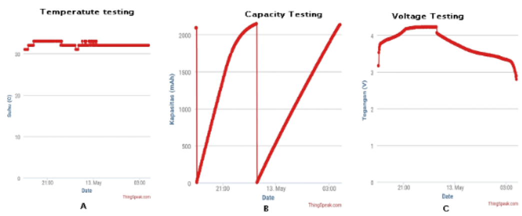

Figure 17. Result Internet of Things (IoT) System Testing

The recapitulation results of testing Battery 1, Battery 2, and Battery 3 using the Fuzzy Logic Tool and Fuzzy Logic Matlab methods are shown in Table 6.

3.5 Internet of Things (IoT) System Testing

The tests taken are in the form of temperature data, Battery capacity and voltage. Then the data is received by ThingSpeak via the internet at 1-minute intervals. Then processed into graphics that can be accessed online via a smartphone. The graphic test results were taken on May 12, 2023, from 19:30 to May 13, 2023, 03:37, as shown in Figure 17.

4. CONCLUSION

After planning and creating a Lithium Ion Battery Health Monitoring System Based on Fuzzy Logic, then carrying out testing and analysis, several conclusions can be drawn regarding the working system as follows. The temperature sensor has an error of 0%, which means that the DS18B20 temperature sensor works according to specifications, namely a tolerance of 0.5 °C. The measurement of capacity which has an error of 10% is still quite good with a working system of complex tools for measuring capacity. Testing the fuzzy logic method which has an error of 5% makes this tool suitable for use in measuring or determining battery health and determining battery damage. A properly functioning Internet of Things (IoT) system can display information on the State of Health (SoH) of lithium-ion batteries on devices and smartphones. Future research could test the application on several different brands in more diverse environmental situations, such as air-conditioned rooms, average-temperature rooms, and rooms with higher temperatures.

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